OPTICAL TRANSPORT SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an optical transport system for transmitting, extracting, and inserting light bi-directionally on a light transmission line, and more particularly to a redundant, non-blocking, bidirectional, multi-channel, protocol independent optical transport system for the simultaneous transfer of multiple, optically encoded signals.

2. Background Discussion

A variety of different topologies are employed to manage the transmission of data on an electrical data bus. Known network topologies include: 1) broadcast, such as utilized on a data bus; 2) point-to-point electrical and optical repeater links, such as seen with the ring configuration; 3) and logical star, where all data is transmitted to and from a central location for retransmission to an intended recipient.

One particular problem with these known network topologies is that they cannot be easily integrated with one another. In essence, once a particular topology and protocol are chosen for managing the transmission and receipt of data on a given network, that topology and protocol must always be used by the network. This lack of adaptability is a particular detrimental problem when new or more useful topologies are developed but cannot be applied to existing data transmission networks which are locked into archaic, less efficient topologies.

Recent advances in data transmission technology have been directed to increasing the bandwidth or data capacity of the network, i.e., increasing the amount of data that can be transmitted by the network.

Physics imposes data rates limits on standard optical networks which encode data in pulses of laser light and dispatch them through wires made of glass. Very fast data rates require very short pulses, which tend to smear into one another as they travel through kilometers of fiber. Electronic devices staggered along the path can clean up the signal, but they are expensive and can work on at most 50 billion bits per second using current technology.

To increase the data capacity, researchers have transmitted many signals simultaneously over a single fiber by encoding them in different wavelengths or channels. Transmission networks that use this technique, known as wavelength division multiplexing (WDM), have boosted the capacity of existing fiber twenty fold or more.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an optical transport system which overcomes the disadvantages of the prior art and takes advantage of the recent advances in wavelength division multiplexing.

Accordingly, it is another object of the present invention to provide a novel, bi-directional, redundant optical transport system configured to provide a non-blocking, bidirectional, multi-channel, protocol independent optical transport system for the simultaneous transmission of multiple optical signals.

It is a further object of the present invention to provide an optical transport system using an unique optical amplification arrangement whereby through-fiber between nodes of the system are doped with a rare earth, such as, for example, erbium to provide sufficient amplification to compensate for coupler splitting losses, splice and connector losses.

One particularly advantageous feature of the present invention is that it provides an advanced bus structure which readily supports the bandwidth and channel capacity requirements of present and future avionics data buses while providing physical redundancy to enhance network survivability.

Another particular advantageous feature of the present invention is that it provides the ability to simultaneously transmit a plurality of information as analog, digital and discrete signals over a single wavelength using a single fiber. In this regard, the invention is capable of the simultaneous, non-interfering transmission over multiple topologies of multiple co-existing protocols each running at independent data rates. Additionally, it features the simultaneous, non-interfering transmission over multiple co-existing topologies of analog, digital and discrete signals.

The present invention relates to an optical transport system that permits one, two or a plurality of different network topologies to be respectively connected by one, two or a plurality of fiber optic transmission lines that each transmit light bi-directionally over each of the one, two or plurality of fiber optic lines. Each fiber optic transmission line is capable of carrying one, two or a plurality of wavelengths and each wavelength can contain one, two or a plurality of analog, digital and discrete signals that are encoded using one, two or a plurality of encoding techniques.

The heart of the present invention is an ingenuous arrangement of passive fiber optic couplers, which when combined with wavelength division multiplexing (WDM) selectively route optical signals in and out of the system at each node thereof as discloses by Applicants co-pending U.S. patent application entitled An Optical Interface Device, Ser. No. 08/831,375, filed Apr. 1, 1997, (the entire disclosure of which is herein incorporated by reference for all purposes). This optical interface device, also sometime referred to as an optical bus interface module (OBIM), is capable of inserting, extracting and transmitting light bi-directionally over one, two or a plurality of fiber optic transmission lines carrying one, two or a plurality of wavelengths over each fiber optic transmission line and each wavelength contains one, two or a plurality of analog, digital or discrete signals that are encoded using one, two or a plurality of encoding techniques.

These and other objects, advantages and features of the present invention are achieved, according to one embodiment of the present invention by a redundant, optical transport system which is configured to provide a non-blocking, bi-directional, multi-channel, protocol independent optical transport system for the simultaneous transfer of multiple optical signals between a plurality data terminal equipment. The optical transport system includes a light transmission line for transmitting light bi-directionally and a plurality of nodes, connected linearly by the light transmission line for receiving, extracting and passing signal light. Each node comprises: data terminal equipment for issuing and receiving electrical signals; an electro-optical interface device, associated the data terminal equipment, for converting electrical signals issued by the associated data terminal to light signals for insertion onto the light transmission light and for converting signal light, extracted from the light transmission line into electrical signals to be received by the associated data terminal; a translation logic device connected between the optical interface device and the data terminal equipment, if required, for performing required protocol translation for the data terminal equipment and an optical interface device, connected to the electro-optical interface device and the light transmission line, for extracting light signals from the light transmission line to be converted into electrical signals by the electro-optical interface device for receipt by the data terminal equipment, for inserting, onto the light transmission line, signal light received from the electro-optical interface

device and for passing signal light bi-directionally on the light transmission line.

The transport system further includes a pumping arrangement, for example, an optical pump source, for inserting excitation light onto the light transmission line; an optical amplifier connector fiber connecting the each of the optical interface devices linearly to one another, wherein the optical amplifier connector fiber is doped with a material which is excited by the excitation light and which emits light having a same wavelength as the light signals when radiated with light signals transmitted bi-directionally by the at least one fiber optic line.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1A** is a block diagram which schematically illustrates the optical transport system of the present invention;

FIG. **1B** is a pictorial representation of the elements comprising the optical transport system of FIG. **1A**;

FIGS. **2** and **3** illustrate arrangements for providing optical amplification within the optical transport system of the present invention;

FIG. **4A** illustrates the configuration of an E/O Interface card in use with yet another embodiment of the optical transport system of the present invention wherein the optical signal is inserted, extracted and passed on two separated but redundant fiber optic lines;

FIG. **4B**, illustrates an EOIC configuration for Mil-Std **1553** avionics element;

FIG. **4C** illustrates an EOIC **117** for ARINC **429** avionic element;

FIG. **4D** illustrates a typical, known ARINC network configuration;

FIG. **4E** illustrates an optical arrangement wherein different optical wavelengths are assigned for each equivalent electrical transmission path;

FIG. **4F**, illustrates an optical arrangement which relies on Time Division Multiplexing (TDM) techniques to eliminate the plethora of optical wavelengths required by the arrangement of FIG. **4E**;

FIG. **4G** illustrates the structure for an EOIC adapted to support video;

FIG. **4H** illustrates an arrangement wherein different wavelengths are assigned to different nodes to provide a topology equivalent to a non-blocking Star configuration using MUX/DEMUXes;

FIG. **4I** illustrates an arrangement where, by using dichroic couplers, the resulting topology for these nodes is that of a Point-to-Point Repeatered Link;

FIG. **5** illustrated an optimum bus interface topology with the specific coupler ratios 80/20 on-line and 50/50 off-line;

FIG. **6** is a plot showing the optimum in-line coupling c_{opt} vs n, where n is the number of nodes;

FIG. **7** is a perspective view illustrating a small rugged enclosure complete with moisture seals for ensures a benign mechanical environment for OBIM's; and

FIG. **8** illustrates component placement for a Mil_Std **1553** type card.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The Optical Transport System—General Description

Referring to FIG. **1A**, a block diagram of a first embodiment of an optical transport system in accordance with the present invention, generally indicated at **111**, is illustrated for extracting, inserting and passing light bi-directionally on a light transmission line, generally indicated at **113**, which comprises at least one fiber optical fiber. The system **111** is designed to permit communication between different electrical devices having differing communication protocols and requirements. The optical transport system **111** preferably forms a broken ring, as shown in FIG. **1A**, to prevent the recirculation of light.

The system **111** comprises a plurality of optical bus interface modules (OBIM's) or optical interface devices **115**, as discloses by Applicants co-pending U.S. patent application entitled An Optical Interface Device, Ser. No. 08/831,375, filed Apr. 1, 1997, (the entire disclosure of which is herein incorporated by reference for all purposes). Each OBIM **115** is an arrangement of passive fiber optic couplers, as will be more fully explained with particular reference to FIG. **4A**, which wavelength selectively route optical signals in and out of the network at each node, generally indicated at A.

The primary purpose of the OBIM's **115** is to facilitate bi-directional data transmission and reception over fiber light transmission line **113** comprising one, two or a plurality of fiber optic lines as will be more fully described hereinafter. The configuration achieving this function is shown in FIG. **4A**. The OBIM's **115** are interconnected, linearly, by the transmission line **113** and constitute a totally optical interface to the system **111**.

The optical signals that are fed in or out of the systems **111** are then processed within the node A through the use of an electro-optical interface card (EOIC) **117** which includes wavelength selective filters, photoreceivers and a laser transmitter or light emitting diode photo-transmitter as will be more fully described hereinafter.

Each EOIC **117** is a device which performs an impedance match between the light and electrical domains. The input and the output of each of the EOIC's **117** are connected to a translation logic card (TLC) **119** which performs the required protocol translation for the data terminal equipment (DTE) **121**, which comprise, for example, a computer, video or telephone device, which each have, for example, different protocol requirements. However, a TLC **119** is not required and the EOIC **117** can interface directly with the memory of each of the DTE **121**. This eliminates approximately two thirds of the interface electronics presently employed for the purpose of transmitting information from one DTE to other DTE's.

Each EOIC **117** is provided for converting the optical signals transported over the transmission line **113** to electrical signals which will be eventually read by the associated DTE **121** and for converting the electrical signals issued by the associated DTE **121** to optical signals for transmission over the optical transmission line **113**.

The EOIC **117**, in addition to performing the electrical-to-optical and optical-to-electrical function, provides the means for signal transfer between bus elements and the work stations through TLC's **119** (intermediate interface cards). A TLC is a device which performs protocol impedance matching between the DTE's and the EOIC's. The protocol can be either the preferred direct digital memory interface, the direct analog sensor interface or a legacy protocol. The TLC **119** is capable of receiving or transmitting and converting one or more protocols. For example, two such cards provide standardized avionics communication protocols for ARINC **429** and Mil_Std **1553**. Two PC based workstations (DTE's **121**) provide data display capability using a multi-window display format for the simultaneous viewing of multiple signals and man-machine interface.

The optical transport system **111** incorporates optical amplification which is powered using a laser pump **123**, emitting light having a wavelength of about 980 nm as will be more fully described with particular reference to FIG. **2**.

The transmission line **113** of the general configuration of the optical transport system **111** illustrated by FIG. 1A, comprises two optical fibers **113'**, **113"** (one serving as a redundant fiber) laid out in a "broken ring" to avoid recirculation of the optical signals. The through fibers at **114** (as best seen in FIG. 4*f*) between each node A are a few meters long and doped with a rare earth, such as, for example, erbium to provide amplification to compensate for all optical losses encountered by an optical signal passing through an OBIM **115** as will be explained hereinbelow. Optical amplification in the erbium doped through fibers is obtained by a "pump" signal provided by laser pump **123** transmitted through the entire system **111**.

FIG. 1B is a pictorial representation of the optical transport system **111** of the present invention illustrated by FIG. 1A.

Arrangement For Pumping The Optical Transport System

Referring to FIG. **2**, a first embodiment of the arrangement for optically pumping the system **111** is shown at **19**. For the sake of simplicity, the OBIM at **11** is shown configured for use with a single fiber optic line **13**.

The arrangement **19** comprises a pump source **21** for inserting excitation light (about 980 nm) onto the transmission line **113** which as noted above, comprises a single fiber optic line **13**, however, the present invention is not limited to a single line **13** and envisions use with two or more fiber optic lines as will be more fully discussed hereinafter.

An optical amplifier **27** for amplifying signal light is also provided which comprises, for example, a connector fiber optic line having a length **1**, for connecting the OBIM **11** with other devices as well as between OBIM's of the system **111**. The connector fiber optic line of the optical amplifier **27** is doped with a material that is excited by the excitation light and that emits light having a same wavelength as the light signals when radiated with light signals.

Erbium is a suitable material for doping the fiber optic line of the optical amplifier **27** because 980 nm excitation light excites erbium atoms in the fiber such that when the excited erbium atoms collapse, 1550 nm light (the same wavelength as the signal light) is emitted. Therefore, when a photon of 1550 nm signal light collides with the excited erbium atoms, one photon of 1550 nm signal light becomes two photons of 1550 nm signal light.

According to the preferred embodiment of FIG. **2**, the pump source **21** is a pump laser which emits excitation light having a wavelength of about 980 nm. As noted above, the signal light has a wavelength of about 1550 nm. The length **1** of the optical amplifier connector fiber is set as a function of the amount of amplification required and in the preferred embodiment of FIG. **2**, the length of the connector fiber of the optical amplifier **27** is about two meters.

The connector fiber of the optical amplifier **27** is used to connect the OBIM **11** to an other device, including, but not limited to another OBIM **11** and can be provided both prior to and subsequent to the OBIM **11**. Further, the connector fiber of the optical amplifier **27** can also be connected to at least one of the extraction port **29** or the insertion port **31** of the OBIM **11**.

Referring to FIG. **3**, a further embodiment of the arrangement **19** for optically pumping an OBIM **11** is illustrated wherein each OBIM **11** is provided with a pump source **21** for emitting excitation light. A coupler **33**, such as, for example, a wave division multiplexer is provided for inserting the excitation light from the pump source **21** onto the at least one fiber optic line **13** to one side of the pair of fiber optic-line, optical couplers **17**, **17'** of the OBIM **11**.

An optical amplifier **27** for amplifying signal light is also provided for receiving excitation light from the pump source **21** as well as signal light transmitted in both directions A or B on the at least one fiber optic line **13**. As described above, the optical amplifier **27** comprises, for example, a connector fiber optic line having a length **1**, for connecting the OBIM **11** with other devices. The connector fiber optic line of the optical amplifier **27** is doped with a material, such as, for example, erbium, that is excited by the excitation light and that emits light having a same wavelength as the light signals when radiated with light signals.

According to the preferred embodiment of FIG. **3**, the pump source **21** is a pump laser which emits excitation light having a wavelength of about 980 nm. As noted above, the signal light has a wavelength of about 1550 nm. The length **1** of the optical amplifier connector fiber is set as a function of the amount of amplification required and in the preferred embodiment of FIG. **3**, the length of the connector fiber of the optical amplifier **27** is about two meters.

The connector fiber of the optical amplifier **27** is used to connect the OBIM **11** to another device, including, but not limited to another OBIM **11** and can be provided both prior to and subsequent to the OBIM **11**. Further, the connector fiber of the optical amplifier can also be connected to at least one of the extraction port **29** or the insertion port **31** of the OBIM.

In lieu of the OBIM **11** of FIG. **2**, it is understood that other OBIM configurations, as disclosed by Applicants' co-pending application noted above, wherein the at least one fiber optic line **13** comprises two or more fiber optic lines, are envisioned for use with present invention.

In order to provide redundancy, the light transmission line **113** of the optical transport system **111** of the present invention preferably comprises a pair of fiber optic lines as best seen in FIG. **4A**. Therefore, if one of the fiber optic lines is broken, the remaining fiber optic line will transmit the signal light.

DETAILED DISCLOSURE OF OBIM STRUCTURE

Referring to FIG. 4A, a preferred arrangement of an OBIM **115** is illustrated for the insertion and removal of light from the transmission line **113**, which in this case, comprises a pair of fiber optic lines **113'**, **113"**, to implement the desired fail-safe operation, (if one line fails, the other line is available to provide the signal light). The OBIM **115** of FIG. **4A** comprises first and second 50/50 couplers **125**, **125'**, one provided for each of the pair of fiber optic lines **113'**, **113"**. The 50/50 couplers **125**, **125'** are provided for receiving light from the EOIC **117** to be inserted onto one of the fiber optic lines **113'**, **113"** or for providing signal light extracted from the lines **113'**, **113"** to the EOIC **117**.

The OBIM **115** also comprises a pair of 80/20 fiber optic-line, optical couplers **126**, **126"**, each coupled directly to one of the fiber optic lines **113'**, **113"** and to one of the pair of 50/50 optical couplers **125**, **125"**, for respectively passing light on the associated fiber optic line **113'** or **113"**, for receiving light from the associated 50/50 optical coupler **125** or **125'** to be inserted onto the associated fiber optic line **113'** or **113"** and for transmitting said received light in opposite directions on the one associated fiber optic line **113'** or **113"**, and for extracting light from opposite directions on the one associated fiber optic line **113'** or **113"** and transmitting said extracted light to the associated 50/50 optical coupler **125** or

125'. An additional 50/50 optical coupler 127 is included for receiving light outputed by the EOIC 117 and providing the received light to the pair of 50/50 optical couplers 125, 125' for insertion bi-directionally on both of the fiber optic lines 113' and 113".

To understand the optical routing achieved by OBIM 115, the following discussion is provided. A signal exiting from the upper left fiber (labeled fiber 113') traveling toward 80/20 coupler 126 is split such that 80% of the signal is passed on fiber 113' to the next node and the remaining 20% is directed toward the EOIC 117. The remaining 20% of light, by action of the associated 50/50 coupler 125 is split equally and routed towards optical filter/receiver combination 129, 131. In a similar fashion, tracing the signal from the EOIC 117, light is split equally by 50/50 coupler 127 and provided to both 50/50 couplers 125, 125' where it is split equally and routed to each bus fiber 113', 113" for insertion thereon in opposite directions simultaneously one each of the fibers 113', 113".

Because two parallel optical paths now exist, optical signals for each will be slightly delayed with respect to each other as a function of path length difference between respective transmitting and receiving nodes. For high frequency operation, these signals must be treated independently, for example, by employing two optical receivers, one dedicated to each path.

Generic EOIC Structure

Located between the OBIM and the DTE 121, the EOIC 117 enables communication between like DTE's 121 located at different nodes of the system 111. As shown in FIG. 4A, the EOIC 117 comprises a pair of optical filters 129, 129' for respectively receiving light signals extracted from the pair of fiber optic lines 113',113". These optical filter, 129, 129', which have, for example a 4 nm passband, precede optical receivers 131, 131', respectively, and pass only the designated wavelength of the corresponding network element (DTE 121 not shown in FIG. 4A) and reject all others. Optical receivers 131, 131' convert the received optical signals into electrical signals. Switch 133 selects one of the electrical outputs from receivers 131, 131' which is then provide to the TLC 119 for processing in order to be compatible with associated DTE 121 as will be more fully explained hereinbelow. Electrical outputs from the DTE 121 are converted to optical signals by the EOIC 117 which are inserted onto the fiber optic lines 113', 113" using the optical amplifier 135.

In a fully operational mode of the system 111, the output of either receiver 131, 131' is valid and the choice as to which to use is arbitrary. However, in the event of a fiber break, the alternative receiver is automatically selected. Each receiver 131, 131' detects and measures the incident input signal and outputs a corresponding digital signal indicating whether or not a minimum input optical power threshold is exceeded. Control logic then monitors these signals and selects the appropriate receiver.

Instead of continuous data transmissions, the system 111, particularly when applied to avionics data bus requires, deals with bursty transmission (high density, clusters or packets of data). Most optical receivers designed for digital transmission incorporate automatic gain control for extending optical input dynamic range. These AGC loops have settling times in excess of many bit periods thereby causing loss of leading bits in a data packet. For continuous data this is generally not a problem, but in discontinuous data transmission, the situation is unacceptable. To get around this problem, the receivers 131, 131' operating on the principle of edge detection, although a penalty is incurred in terms of loss of optical sensitivity.

The details of the optical and electro-optical system for implementing simultaneous multi-network operation using multiple optical carriers over a single fiber implementation are also shown in FIG. 4A. The technical approach exploits the two low attenuation windows of step index single mode optical fiber, 1310 nm and 1550 nm. By means of narrow bandwidth optical sources, temperature controlled distributed feedback lasers, and complementary narrow band optical filters, multiple interfering optical carriers are realized in the 1550 nm operating band.

Therefore, it is possible to provide four channels within the 1550 nm operating band which each have center wavelengths at, for example, 1536 nm, 1543 nm, 1550 nm, and 1557 nm, each channel being capable of carrying different signal light imparting distinct information. Optical carrier encoding techniques supported by this architecture include signal formats such as Pulse Code Modulation (PCM), intensity modulation (IM) coherent or incoherent, amplitude, phase and frequency modulation.

Specific EOIC Structure For Mil_Std 1553

In addition to optical filtering and E/O and O/E conversion, the EOIC 117 is adapted to provide the required data encoding functions to convert the ARINC 429 and Mil_Std 1553 three-level codes to two level codes. In the electrical domain, these signals are encoded as tri-level signals and then converted to bi-level signaling with subsequent bandwidth increase. Although optical intensity modulation (IM) supports multi-level encoding, the preponderance of commercial optical receivers are designed for bi-level operation.

The encoding and decoding function is performed by the EOIC 117 which includes an on-board gate array containing conversion circuity for both data types. In the present embodiment of the system 111, four data types transit the optical transport system 111: three digital and one FM video.

As shown in FIG. 4B, an EOIC configuration for Mil_Std 1553 avionics element is shown. The EOIC 117 contains a number of hardware components for the transmission and reception of bus 113 signals, data encoding, traffic control and optical transmission and reception as discussed below.

Mil_Std 1553 line receiver 135 converts the bi-polar bus signal to digital logic level and line driver 135' converts logic level signals to bi-polar signals levels conforming to Mil_Std 1553 specifications.

Encoding optical transmission of the MIL-1553 bus messages requires converting the three state electrical signal to a two state optical signal which is accomplished by FPGA 137. MIL-1553 bus transmission medium is a twisted pair wire. Signal states present on the wire include a NULL state signifying inactivity, and two active states for the transmission of 1's and 0's. Thus, voltage across the two wire has three possible states. For optical transmission of the signal, it must be encoded in a waveform with only two states. Another requirement of the coding is that it must have zero DC content for any combination of sync patterns, ones and zeros. The encoding concept is to frequency encode the three states by assigning one frequency to denote the logical ONE, another frequency to denote a logical ZERO and a third frequency (0 Hz) to denote no transmission.

The laser drive and temperature control 139 performs two functions: 1) laser modulation and 2) laser temperature control. The laser driver converts the digital input signals from the FPGA 137 to current pulses used to modulate the laser. The resultant optical signal intensity waveform is representative of the digital input signal. The purpose of the laser temperature control is to maintain the laser at a constant temperature. DFB laser wavelength dependence is